DIY 3D Scanner

IE 594: Advance 3D Printing/Additive Manufacturing

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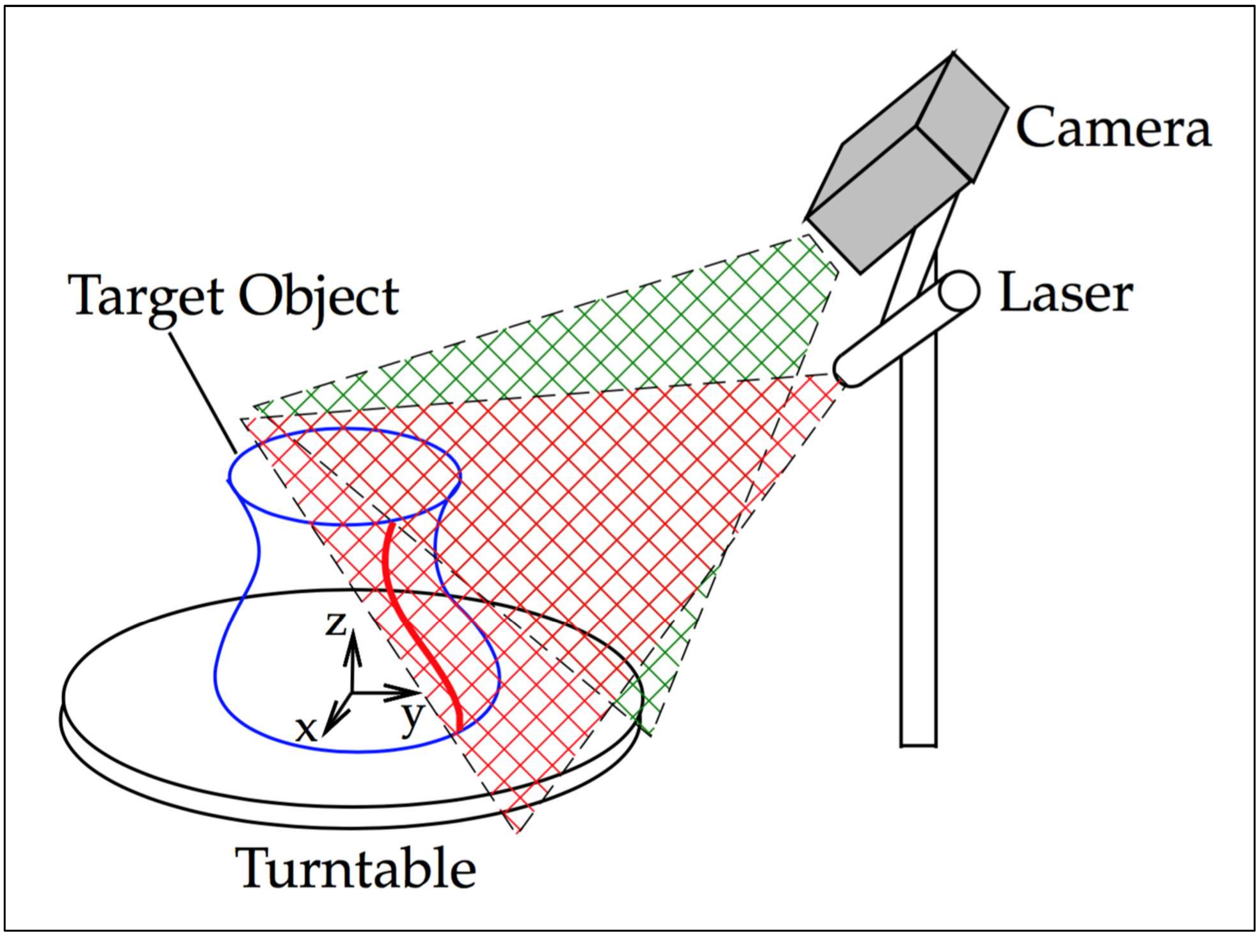
Table of Contents

Introduction

3D scanning is the process of analyzing a real-world object or environment to collect data on its shape and possibly its appearance (e.g. color). The collected data can then be used to construct digital 3D models.

A 3D scanner can be based on many different technologies, each with its own limitations, advantages and costs. Many limitations in the kind of objects that can be digitized are still present. for example, optical technology may encounter many difficulties with shiny, reflective or transparent objects. For example, industrial computed tomography scanning and structured-light 3D scanners can be used to construct digital 3D models, without destructive testing.

Collected 3D data is useful for a wide variety of applications. These devices are used extensively by the entertainment industry in the production of movies and video games, including virtual reality. Other common applications of this technology include augmented reality, motion capture, gesture recognition, industrial design, orthotics and prosthetics, reverse engineering and prototyping, quality control/inspection and the digitization of cultural artifacts.

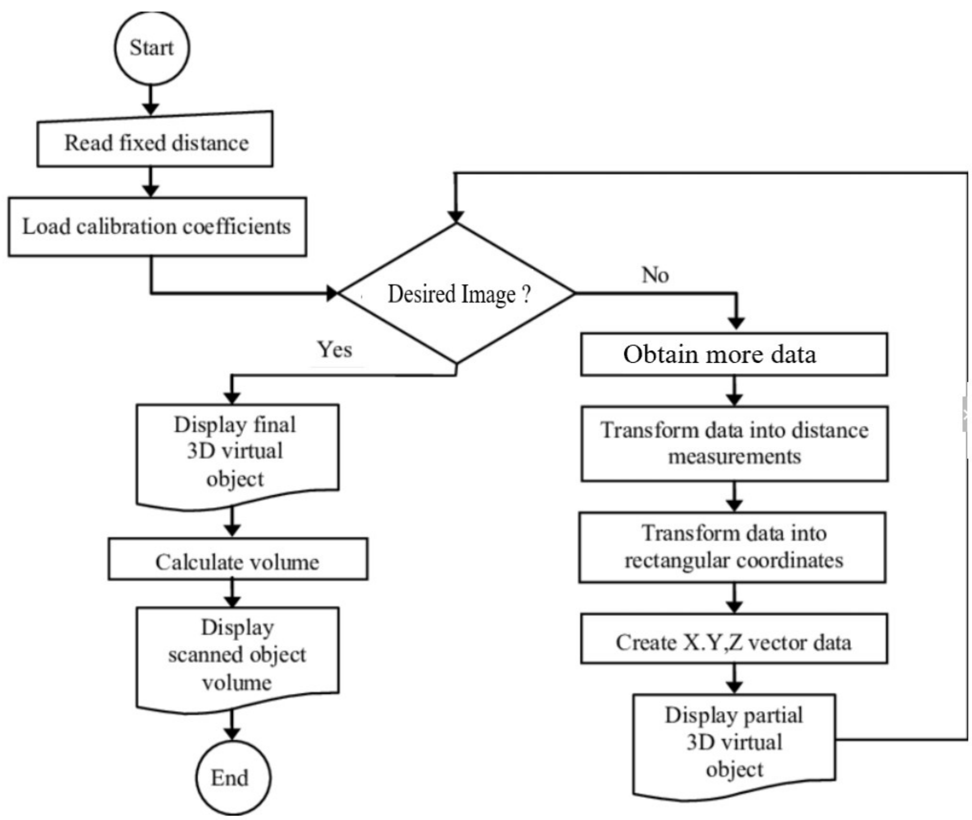


Functionality

The purpose of a 3D scanner is usually to create a 3D model. This 3D model consists of a point cloud of geometric samples on the surface of the subject. These points can then be used to extrapolate the shape of the subject (a process called reconstruction). If color information is collected at each point, then the colors on the surface of the subject can also be determined.

3D scanners share several traits with cameras. Like most cameras, they have a cone-like field of view, and like cameras, they can only collect information about surfaces that are not obscured. While a camera collects color information about surfaces within its field of view, a 3D scanner collects distance information about surfaces within its field of view. The "picture" produced by a 3D scanner describes the distance to a surface at each point in the picture. This allows the three-dimensional position of each point in the picture to be identified.

For most situations, a single scan will not produce a complete model of the subject. Multiple scans, even hundreds, from many different directions are usually required to obtain information about all sides of the subject. These scans have to be brought into a common reference system, a process that is usually called alignment or registration, and then merged to create a complete 3D model. This whole process, going from the single range map to the whole model, is usually known as the 3D scanning pipeline.



What is 3d scanning technology?

3D scanning is a technique used to capture the shape of an object using a 3D scanner. The result is a 3D file of the object which can be saved, edited, and even 3D printed.

The basic principle is to use a 3D scanner to collect data about a subject. The subject can be an object an environment (such as a room) a person (3D body scanning). Some 3D scanners can simultaneously collect shape and color data. A 3D scanned color surface is called a texture. A 3D scan can give a lot of information about the design of an object, in a process called reverse engineering.

3D Scanning Technologies and Processes

3D scanning is a technique used to capture the shape of an object using a 3D scanner. The result is a 3D file of the object which can be saved, edited, and even 3D printed. Many different 3D scanning technologies exist to 3D scan objects, environments, and people. Each 3D scanning technology comes with its own limitations, advantages, and costs.

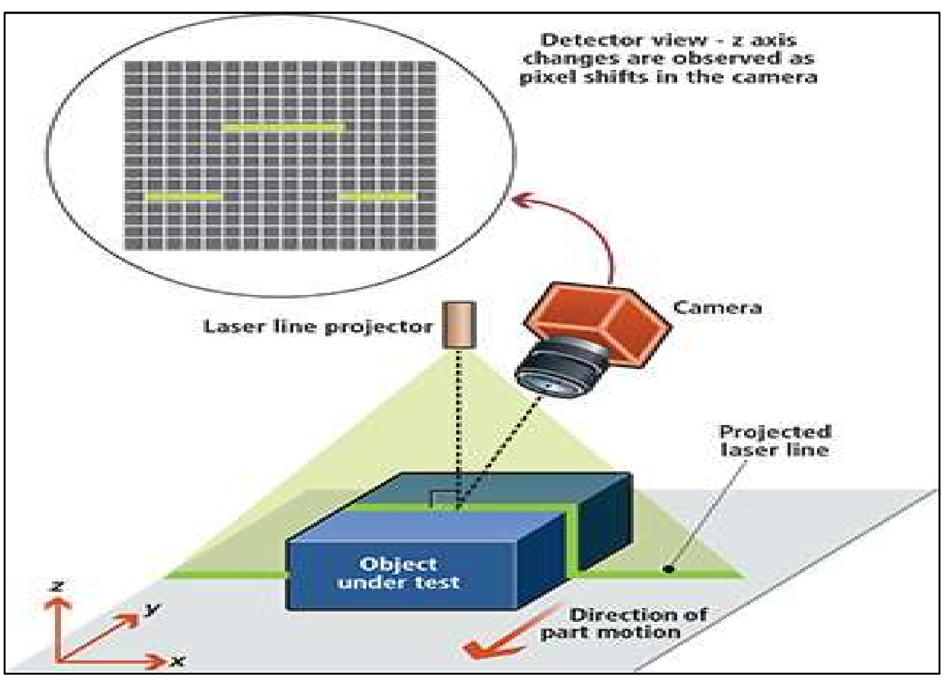
The basic principle is to use a 3D scanner to collect data about a subject. The subject can be:

- An object
- An environment (such as a room)
- A person (3d body scanning)

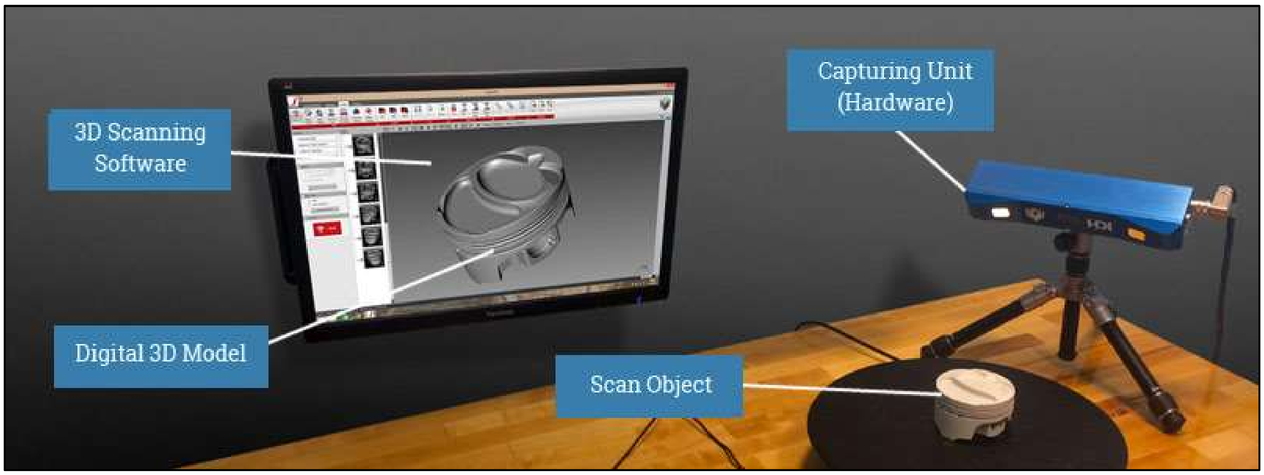
3D Scanning Categories:

1. Laser triangulation 3D scanning technology, as illustrated on the image, projects a laser beam on a surface and measures the deformation of the laser ray.
2. Structured light 3D scanning technology measures the deformation of a light pattern on a surface to 3D scan the shape of the surface.
3. Photogrammetry, also called 3D scan from photographers, reconstructs in 3D a subject from 2D captures with computer vision and computational geometry algorithms.
4. Contact-based 3D scanning technology relies on the sampling of several points on a surface, measured by the deformation of a probe.
5. Laser pulse (also called time of flight) 3D scanning technology is based on the time of flight of a laser beam. The laser beam is projected on a surface and collected on a sensor. The time of travel of the laser between its emission and reception gives the surface's geometrical information.

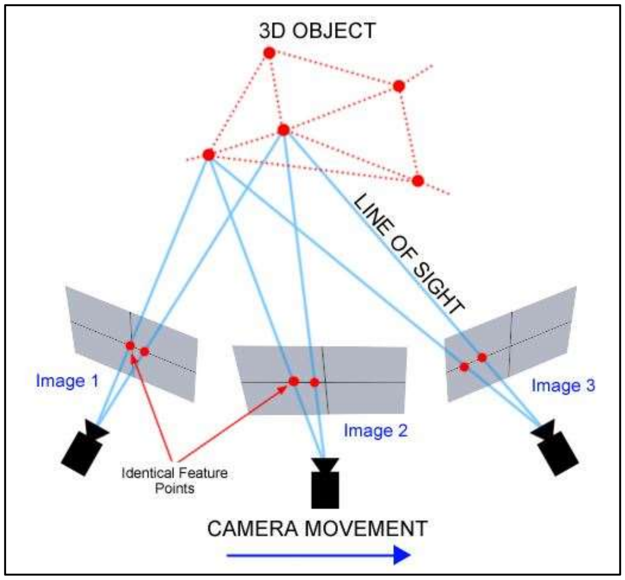
1. Laser triangulation 3D scanning technology
   - The laser is first cast by the 3D scanner. As the laser light reflects off the 3D scanned object, its initial trajectory is modified and picked up by a sensor.
   - From the modification of the laser trajectory and trigonometric triangulation, the system can discern a specific deviation angle.
   - When the 3D scanner collects enough distances, it is capable of mapping the surface's object and of creating a 3D scan.
   - Advantage: High accuracy and resolution.
   - Disadvantages: It is sensibility to the properties of the surface to 3D scan. Very shiny or transparent surfaces are particularly problematic.



2. Structured light 3D scanning technology
    - The technology here is created by casting geometric patterns onto an object while simultaneously taking images with a camera.
    - When doing so, the camera logs the deviation of the image. Based on this displacement of the pattern, locations of all existing points are able to be determined. Numerous scans have to be conducted from different positions and then combined until the mesh can be 100% complete.
    - The structured light used for 3D scanning can be white or blue and generated by numerous types of projectors, such as Digital Light Processing (DLP) technology. The projected pattern is usually a series of light rays but can also be a randomized dot matrix.
    - Advantage: Speed, resolution, and ability to 3D scan people.
    - Disadvantages: its sensibility to lighting conditions and issues to work outside.

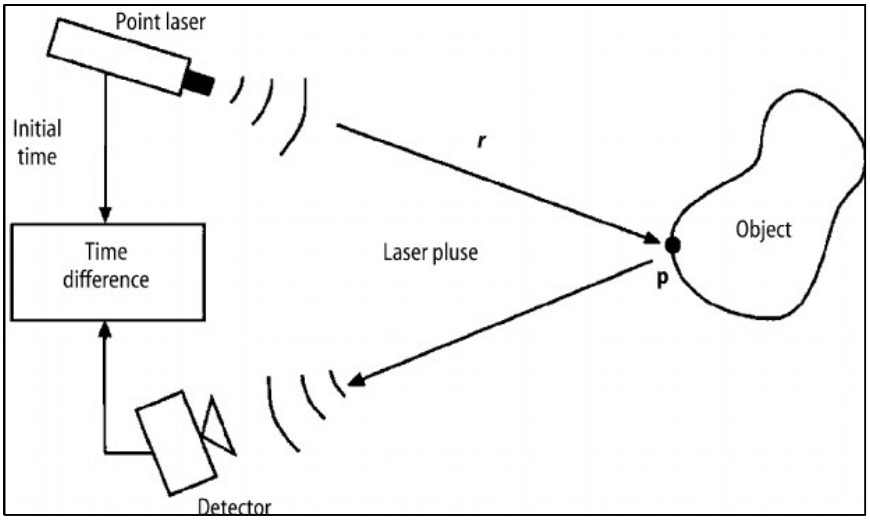


3. Photogrammetry:
    - Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points. Photogrammetry is based on a mix of computer vision and powerful computational geometry algorithms. The principle of photogrammetry is to analyze several photographs of a static subject, taken from different viewpoints, and to automatically detect pixels corresponding to a same physical point.
    - Advantages: its precision and acquisition speed, capable of reconstructing subjects of various scales, photographed from the ground or from the air.
    - Disadvantages: its sensitivity to the resolution of the input photographs and the time it takes to run the algorithms.



4. Contact-based 3D scanning technology
    - Contact 3D scanners probe the subject through physical touch, while the object is firmly held in place.
    - A touching probe is moved on the surface to various points of the object to record 3D information. The probe is sometimes attached to an articulated arm capable of collecting all its respective configurations and angles for more precision.
    - Some specific configurations of contact-based 3D scanners are called Coordinated Measuring Machines (CMM).
    - Advantages: precision and ability to 3D scan transparent or reflective surfaces
    - Disadvantages: its speed and inadequacy to work with organic, freeform shapes.

5. Laser pulse (also called time of flight) 3D scanning technology:



- The Laser pulse-based 3D scanners, also known as Time-of-Flight scanners or Lidar, measure how long a casted laser takes to hit an object and come back. Because the speed of light is exactly known, the time it takes for the laser to do the way back gives the exact distance between the 3D scanner and the object.
- In order to precisely measure the distance, the 3D scanner computes millions of laser pulses with picosecond accuracy.
- Since each measure only collects one point, the 3D scanner needs to cast its laser 360 degrees around that point. To perform this feature, the 3D scanner is usually fitted with a mirror which changes the orientation of the laser.
- Advantage: ability to 3D scan very big objects and environments.
- Disadvantage: Very Slow.

Applications of 3D scanning

The reasons for 3D scanning are incredibly diverse. Everywhere it's applied, 3D scanning can measure, document, and record precise data about the physical world. Applications of 3D scanning technologies in different industries and disciplines are:

1. Manufacturing

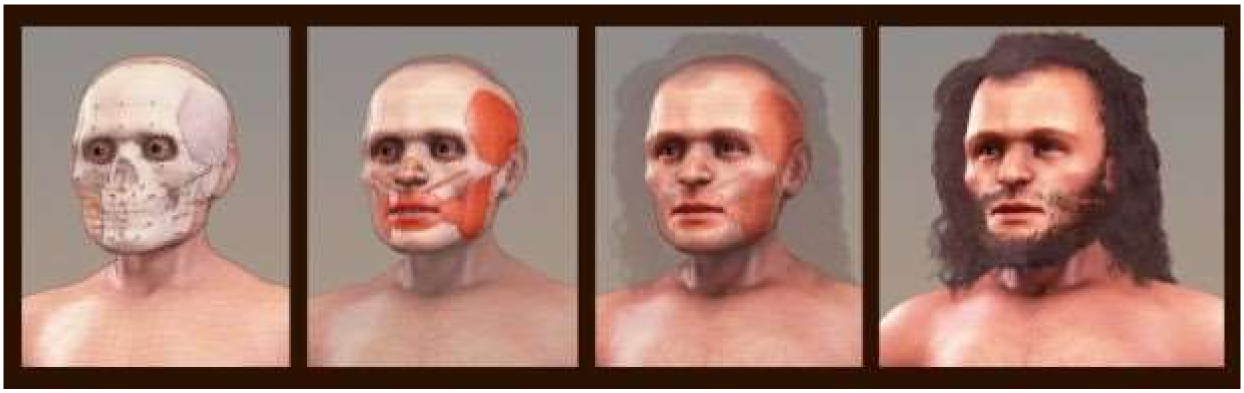
Aerospace was one of the earliest adopters of 3D scanning (and remains a leader) but most earth-bound manufacturing processes now also incorporate 3D laser imaging to inspect equipment or aid in reverse-engineering or prototyping. Fields that involve hazardous environments, like power generation and nuclear, doubly appreciate the hands-off nature and hustle 3D scanning provides.

2. Medical

In the medical world, one of the greatest benefits of 3D scanning is increasing patient comfort with the customization of wearable devices – braces, implants, prosthetics, etc. It is also non-invasive technology that produces consistent results, requiring little time and no physical contact with patients. The boon of being quick and non-invasive also applies in the field of forensics, where 3D scanning is used to record information about crime and accident scenes. The most important application of 3D scanning in medicine is the 3D ultrasound – specifically its ability to create 3D photos in obstetrics.

3. 3D Scanning for scientific study:

Another classic example of how a 3D scan can aid the scientific community in a creative way is their use in modeling the facial features of our evolutionary ancestors. Today, the modeling takes place in software programs like Blender rather than with clay on a cast form– in 2013 ATOR (Arc-Team Open Research) performed this incredible trick again using the fossil of a cro magnon man.



Motivation

3D Printing is one of the most emerging fields of manufacturing industry. The field has been developing a lot since last 10years.Emense research and study has been done in this field. 3D printing has emerged to be the next big thing. By 3D printing it has become easy for designers and engineers to get to perfection in less time. Results have become time bound and efficient output of work is ensured.

3D printing gives you the liberty and freedom to think broadly, all that is imagined can be brought into matter. Various process and techniques are been used to do 3D printing. Some of them are listed below.

- Vat-Photopolymerization
- Stereolithography (SLA) Digital Light Processing (DLP)
- Material Extrusion. Fused Deposition Modeling (FDM)
- Powder Bed Fusion. Selective Laser Sintering (SLS)

For each of the above process to be executed a CAD file is required to be given as an input, this leads to a limitation on the use of this technology. To overcome this 3D scanners can be used for which you do not require the skill to make a CAD model, this led us to find out what kind of 3D Scanners are available and what is the scope of its use. Project objective to compare different 3D scanners and analyze their results is further discussed in the report.

DIY 3D Scanners

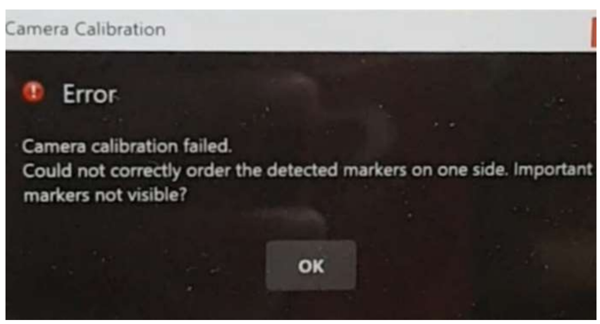
Type 1: Hand held laser scanner

Tools used:

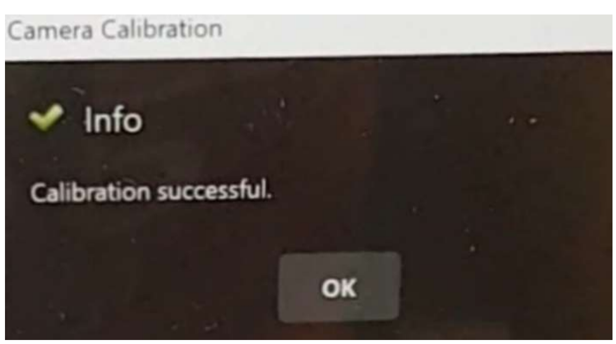
- 1 laser line
- Laptop camera
- Calibration boards

To understand the process of laser scanning we started with the most basic configuration. There was different imaging processing software to use such as Sardauscan and DavidScanner (Now is called HP Laser scanner). We decided to use the DavidScanner due to different errors occurred in the other software's. We used the trial version which offers limited imaging resolution.

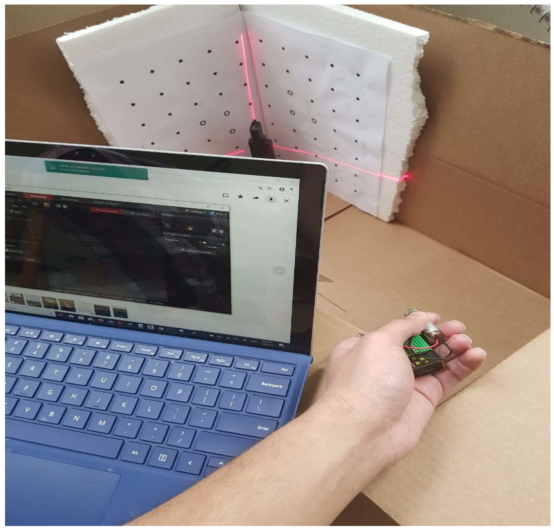
In the beginning, we had to setup the calibration board so the camera can detect the pinpoints of the desired object scanned. Many problems occurred during this setup. The Sardauscan software wasn't detecting the calibration board so the DavidSscanner software was used. At first, the camera calibration was still not working. The error message reported was "Camera calibration failed. Could not correctly order the detected markers on one side. Important markers not visible?". Multiple solutions were applied from light adjusting to changing the cameras but non proved to work.



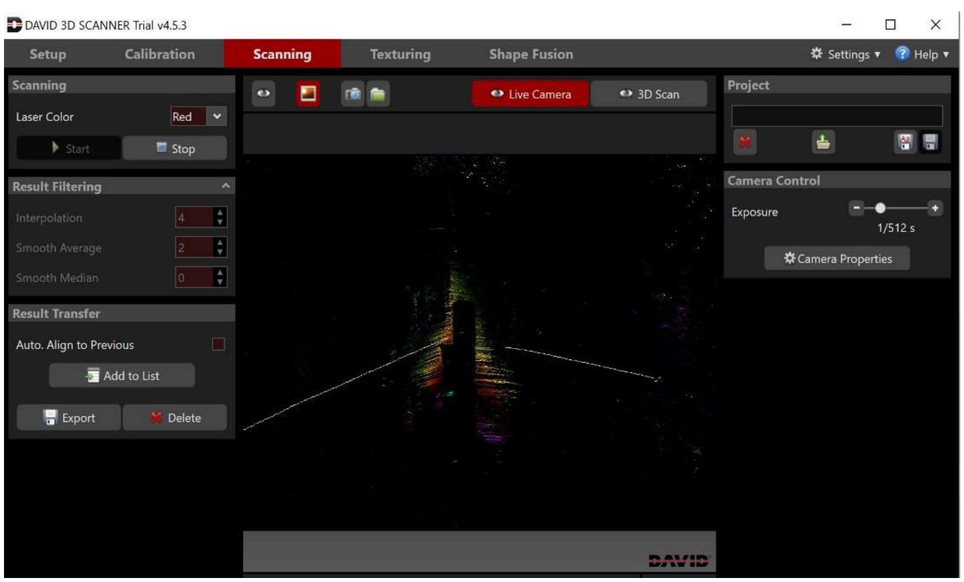
After multiple tries, we tried to change the calibration board sheet to a different one and make the sheet size bigger. Moreover, the light exposure function implemented in the program helped in adjusting the light. By applying these changes, the camera calibration was successful.



The next step was to place the desired object to be scanned in front of the calibrated sheet. Then we click the start button in the Davidscanner program to start the scanning process. After completing this process of calibration and placing the object, we point the handheld laser into the object. This will prompt the program to detect the laser line and start scanning.



As you move the laser from top to bottom, the image of the scanned object should appear in the display page. This process takes about 5 to 10 minutes to complete. Unfortunately, due to some unknown reason that may be related to lightning or laser effectiveness, the resulted scans didn’t appear to be accurate nor demonstrate the desired object relatively correct.



Obstacles:

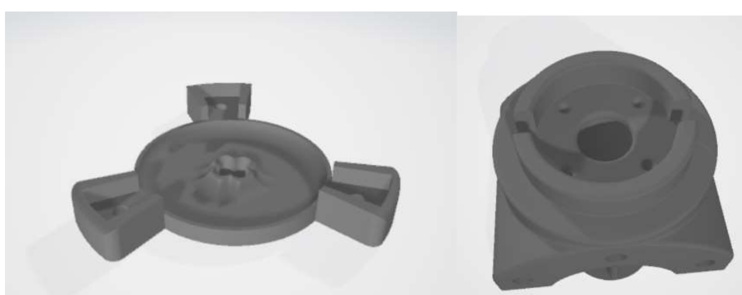
1- Limited software.
2- Holding a handheld laser can be tiring because the software can't detect every angle and the hand must be steady constantly.
3- Multiple calibration tests must be performed to get a successful result.
4- Scanned images appear to be missing key components of the object.

Type II: Laser Scanner using two-line lasers

Construction:

The scanner setup has two parts, the firmware or the code to read the lasers and second are the entire scanning setup. The setup consists of a several parts mainly:

1) Rotating table: The rotating table is driven by a stepper motor which is controlled using an Arduino. The motor is placed vertical to the ground and a housing and support is designed and 3D printed. The shaft is then sent out of the housing and a circular disc is mounted on it with the support of a bearing. When the motor shaft rotates, the disc rotates, and the required object rotates. The motor feed rate is controlled by the firmware from the computer.



Parts 3d printed for rotating table

2) Laser holder: We are using two-line lasers which are placed at a distance facing towards the center of the turning table. The base of the laser holder is 3d printed. Four rods are then inserted into the holder, two on each side of the base tower. The laser holding mounts are then attached to the both ends, and the lasers are then attached.

3) Camera: We are using a Logitech C90 web-camera for taking the images at 480p. The resolution is low as it takes a very high memory and computation power of the computer for processing for high definition photos. The camera is mounted in the middle of the base tower.
4) The laser holder and the motor support base are connected using 3 rods. These are connected using nuts and washers for providing support for the laser baser.

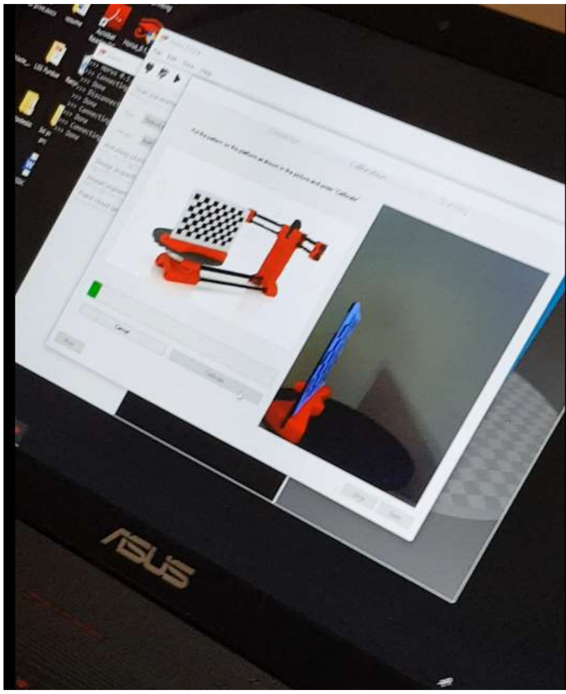
Circuit and connections:

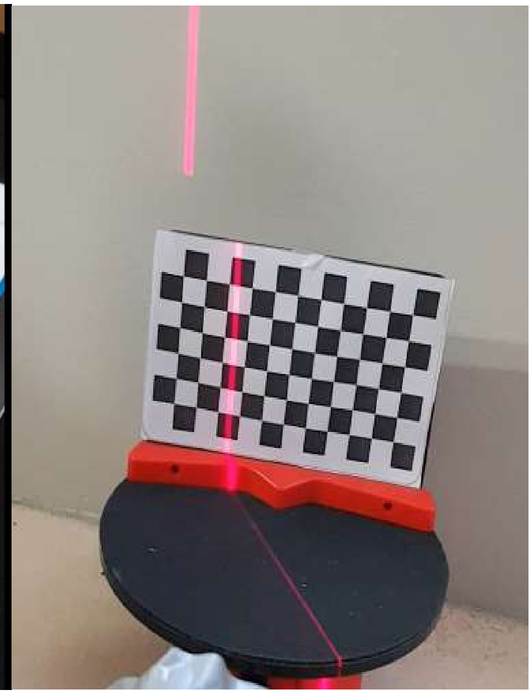
The lasers are connected to the Arduino A1,A2 ports and the motor is connected to the motor pins in the Arduino using connecting wires. The motor is powered using a USB to a computer.

Software: The software we use is obtained from GIT HUB open source. It is known as Horus. It is mid-level laser detection software. It recognizes the lasers, and the photos taken by the camera and combines the laser lines to form the required image.

Calibration:

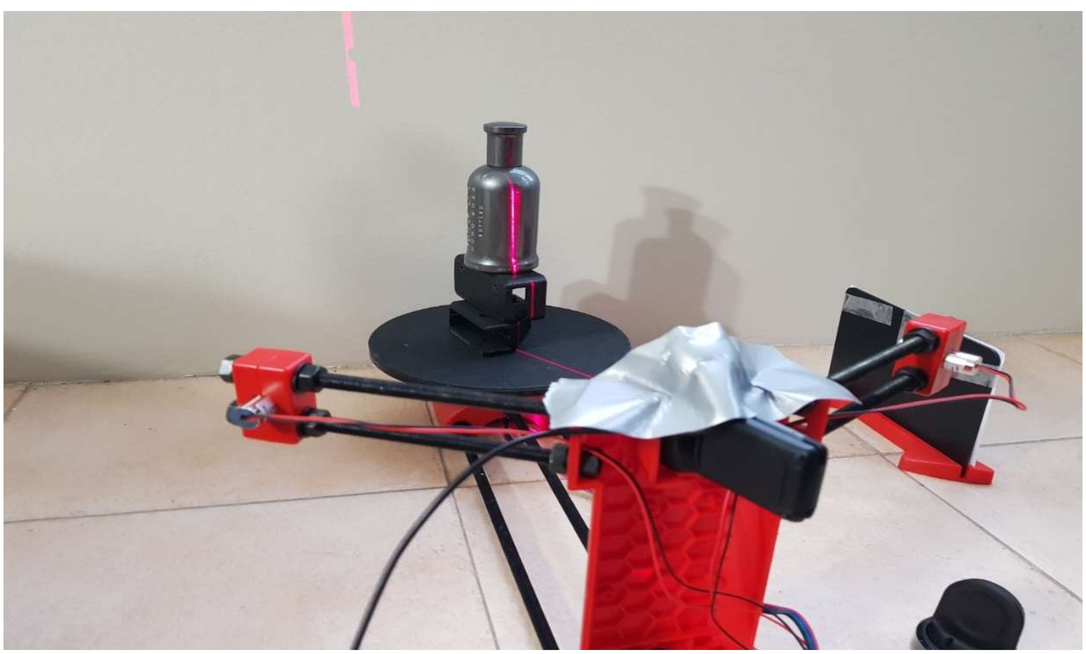
The calibration of the camera and the setup is the main step in the entire scanning process. We start by preparation of the calibration sheet. That is a grid and we pit the sheet in front of the camera and run the software to calibrate. The software detects the lines and dark places and registers. The calibration sheet is placed 37 mm from the base of the turning table. The camera is finally calibrated.



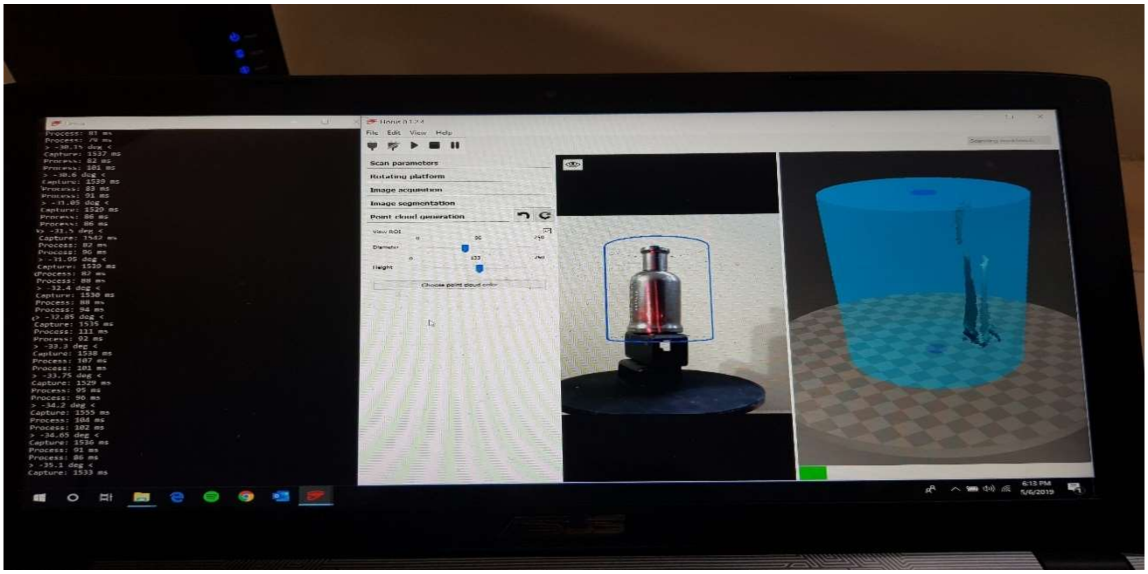


Results:

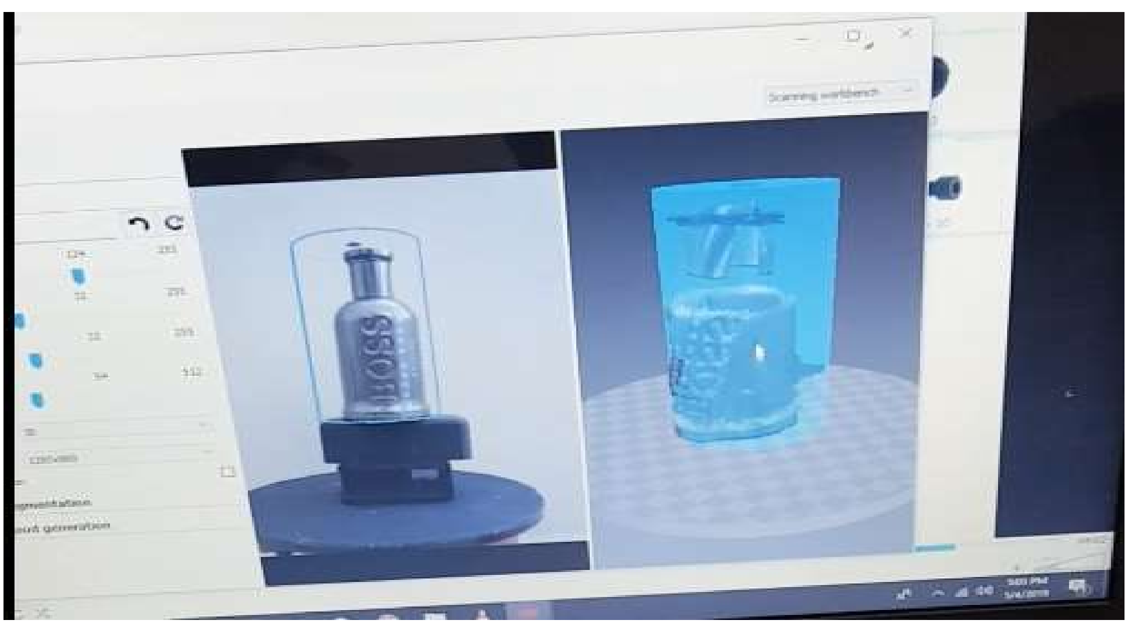
The laser scanner works on the principle of Laser Triangulation method. The camera first takes an image of the object without using lasers to create a base image. Then at every step an image is taken with laser fired.



Now the software computes the laser lines on the object and forms an image in the computer. Now the object is rotated 360 degrees multiple times slowly. We used 100 steps for the motor. The accuracy increases with increasing number of steps.



The entire object is now completely scanned multiple times and the laser lines at every step are computed. The software then merges all the lines to from the object. The main issue is the formation of the points in the point cloud and this is sometimes not accurate due to the position of lasers, camera intensity, outside exposure, laser intensity being low and many more factors. We have performed the experiment multiple times to generate a good scan, but the laser lasers we used do not have high intensities and the software is not very sophisticated. The points that are generated in the point cloud are then meshed in the software called mesh mixer later to form an STL file.



This is the output of the final scan and shown are the points in the point cloud. These are then meshed together in the mesh-mixer or any software design for the required object. The time taken to scan the entire bottle is around 21 minutes and the time varies with the size of the object and the point cloud.

Type III: Photogrammetry

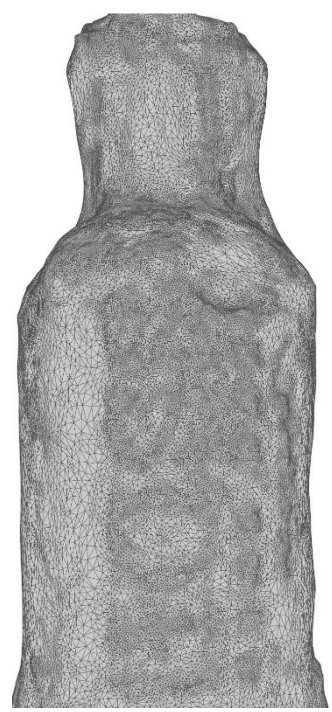
Tools used:

- Camera phone
- Autodesk Recap Photo software

This process of scanning an object is the simplest of all types mentioned in this project. The steps for this process are as follows:

1- Place the desired object to be scanned on a table.
2- Use the phone camera to take multiple images of the object from all sides.
3- Upload images to the Recap Photo software
4- The rendering process takes about 10 to 30 minutes to be complete depending on how many images are processed.
5- The 3D shaped scan appears on screen.

(3D Shaped object)



(Mesh image of object)

The scanned image results are relatively good but due to instability in image taking and some other factors, some parts surrounding the object are shown as if they are a part of it. Editing must be done to remove the extra parts. Tools in the software can help in deleting extra components or adding missing parts of the object.

Obstacles:

1- Images have to be taken from the same distance and height of the object while rotating around it to get all sides.
2- Software mistakes the surface contacting the object as part of the object.

Conclusion

We have seen three different cases and the comparison of the images generated of the same object in all the cases. There are few main points we concluded after performing several trails:

1) Among all the three cases, the photogrammetry i.e. in the case- 3 the scans are more accurate. This is because we used a high-resolution camera and a high-end sophisticated image stabilizing inbuilt software. Whereas in cases 1 and 2 we used a sing laser or two lasers and detected points in the point cloud to form an image.
2) The time taken is very less in case-3. In case two was around 22 minutes but in case-1, it takes hours to detect the points as we are using only a single laser which a very poor- recognition software.
3) The construction time in the third case is very minimal as the smartphone is portable and all it required was taking images. In cases of 1 and 2, The setup preparation, calibration and setup take a long time and should be accurate.

Hence, we conclude that, using the photogrammetry is a best solution among the three cases. In the case -2 use of image stabilization algorithms and deep learning techniques for image recognition and image re-construction, the time and accuracy can improve at a very great extent.

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